OPTICAL SOURCE HAVING INTEGRAL DIFFRACTIVE ELEMENT

Background of the Invention

Known light sources that use LEDs (light emitting diodes) pattern emitted light using refractive or reflective structures. Common refractive structures, as shown in the light source of Figure 1A, include dome-profile encapsulants 1 that encase the LED. The emitted light pattern is influenced by the shape of the refractive structure and is typically controlled by making the refractive structure spherical, aspherical or oval. Another common light source (shown in Figure 1B) includes a flat-top encapsulant 2, forming an air-gap device. While the shape of the flat-top encapsulant 2 enables the light source to be compatible with higher level packaging and assemblies, the shape provides only limited refraction and correspondingly little patterning of the light emitted by the LED.

Light sources also include reflective optical structures to pattern light emitted by an LED. For example, LEDs are commonly positioned in a parabolic reflector cup 3 as shown in Figure 2. Alternatively, optical elements based on total internal reflection (not shown) as taught by U.S. Patent No. 5, 592, 578 to Richard A. Ruh can be positioned in the optical path of an LED to pattern the emitted light.

Summary of the Invention

An optical source according to embodiments of the present invention has an optical emitter and a diffractive element integral with an encapsulant. Alternative embodiments of the present invention are directed toward a method for generating an optical radiation pattern.

Brief Description of the Drawings

Figures 1A-1B show prior art LEDs that include refractive structures.

Figure 2 shows a prior art LED that includes a reflective optical structure.

Figure 3 shows an exemplary diffraction grating.

Figures 4A-4D show optical sources according to embodiments of the present invention.

Figures 5A-5E show detailed views of exemplary grating profiles of diffractive elements suitable for inclusion in the optical sources according to the embodiments of the present invention.

Figure 6 shows a method for generating an optical radiation pattern in accordance with alternative embodiments of the present invention.

Detailed Description

Diffraction of light by diffraction gratings, slits and other obstacles having physical dimensions on the order of the wavelength of the incident light is well known. Figure 3 shows an incident optical signal 5 illuminating a diffraction grating 6. The diffraction grating 6 in this example has uniformly-spaced alternating transmissive segments 8 and opaque segments 9. The transmissive segments 8 in this diffraction grating 6 form an array of slits or apertures. Diffraction of the incident optical signal 5 by the diffraction grating 6 is characterized by the grating equation:

$$d(n_2 \sin\alpha - n_1 \sin\theta) = m\lambda$$

where d is the distance between adjacent transmissive segments 8, or slits, of the diffraction grating 6; n_1 is the refractive index of the medium containing the incident optical signal; n_2 is

the refractive index of the medium containing diffracted beams 7; α is the incident angle of the incident optical signal 5; θ represents the diffraction angle of corresponding diffracted beams 7; m is the diffraction order of the corresponding diffracted beams 7; and λ is the operating wavelength of the incident optical signal 5 and diffracted beams 7.

The grating equation illustrates that optical radiation patterns that may be impractical to achieve with refractive or reflective structures may be readily achieved by diffracting the incident optical signal 5. Examples of optical radiation patterns formed by the diffracted beams 7 resulting from diffraction of optical signals 5 by apertures and gratings having various geometries are presented in *Introduction to Fourier Optics*, by J.W. Goodman, pages 62-74, published by McGraw-Hill, Inc., Library of Congress Catalog Number: 68-17184.

According to embodiments of the present invention shown in Figures 4A-4B, optical sources 10, 20, 30, 40 include diffractive elements 12 illuminated by optical signals 13 from optical emitters 14. The diffractive elements 12 diffract the optical signals 13 to form optical radiation patterns 37. The diffractive element 12 in each of the optical sources 10, 20, 30, 40 is integral with an encapsulant 18 that covers the optical emitter 14. Typically, the encapsulant 18 is epoxy or other transparent polymer cured via radiation, pressure or thermal treatment. However, the encapsulant 18 is alternatively any other optically suitable encapsulating material that encases the optical emitter 14.

The optical emitter 14 included in the optical sources 10, 20, 30, 40 is typically an LED, laser diode, or an array of LEDs and/or laser diodes. The optical signal 13 provided by the optical emitter 14 passes through the encapsulant 18 to the diffractive element 12. The diffractive element 12 is typically cast or transfer molded onto an outer surface 16 of the encapsulant 18, thereby integrating the diffractive element 12 into the encapsulant 18.

In the optical source 10 of Figure 4A, the optical source 10 includes the optical emitter 14 positioned at a conductive mounting site 17 of a conductive lead 19. The optical source 20 of Figure 4B differs from the optical source 10 of Figure 4A in that the conductive mounting site 17 of the conductive lead 19 has a reflective cup or well, into which the optical emitter 14 is mounted.

In the optical source 30 of Figure 4C, the optical emitter 14 has a mounting site 17 that is on a conductive heat sink 32, making the optical source 30 compatible with surface mount technologies and processes. The optical source 30 also includes an insulating substrate 34 that isolates the conductive heat sink 32 from a conductive contact 36. The optical source 40 of Figure 4D differs from the optical source 30 of Figure 4C in that the mounting site 17 of the conductive heat sink 32 includes a reflective cup or well, into which the optical emitter 14 is mounted.

The optical radiation patterns 37 produced by the optical sources 10, 20, 30, 40 are established by the characteristics of the optical signal 13 provided by the optical emitter 14 and the attributes of the diffractive element 12. The characteristics of the optical signal 13 provided by the optical emitter 14 can be tailored by the physical arrangement of one or more optical emitters 14 in an array, or by including one or more lenses, focusing elements, reflective elements or refractive elements in the path of the optical signal13 between the optical emitter 14 and the diffractive element 12. The characteristics of the optical signal 13 can also be tailored by florescent dyes, phosphors or other secondary emitter in the path of the optical signal 13. When included in the optical sources 10, 20, 30, 40, the secondary emitter is deposited or integrated onto the optical emitter 14 or into the encapsulant 18.

The attributes of the diffractive element 12 can be tailored based on the grating profile of the diffractive element 12. Figures 5A-5E show exemplary grating profiles for the diffractive element 12. Figure 5A shows the diffractive element 12 having a binary grating profile, wherein the optical signal 13 provided by the optical emitter 14 is diffracted according to alternating steps in the grating profile. In Figure 5B, the diffractive element 12 has a blazed, or sawtooth grating profile, wherein the optical signal 13 provided by the optical emitter 14 is diffracted according to a series of ramps in the grating profile. In Figure 5C, the diffractive element 12 has a sinusoidal grating profile wherein the optical signal 13 provided by the optical emitter 14 is diffracted according to sinusoidal thickness variations in the grating profile. In Figure 5D, the diffractive element 12 has a multiple phase-level grating profile wherein the optical signal 13 provided by the optical emitter 14 is diffracted according to stepped thickness variations in the grating profile. In Figure 5E, the diffractive element 12 has a binary subwavelength grating profile wherein the optical signal 13 provided by the optical emitter 14 is diffracted as described in *Vector-based Synthesis Of Finite Aperiodic Subwavelength Diffractive Optical Elements*, by Prather et al., Journal of the Optical Society of America, Vol. 15, No. 6, June 1998, hereby incorporated by reference. While the grating profiles of Figures 5A-5E are exemplary, diffractive elements 12 having other grating profiles are alternatively included in the optical sources 10, 20, 30, 40.

The optical characteristics or attributes of the diffractive element 12 can also be varied based on the material used to form the diffractive element 12, or by embedding optically opaque material in the encapsulant 18 at physical separations on the order of the operating wavelength λ of the optical signal 13 incident on the embedded optically opaque material which can be used to customize or synthesize a desired optical radiation pattern 37.

Alternative embodiments of the present invention are directed to a method for generating an optical radiation pattern 37, as shown in Figure 6. Step 62 of the method 60 includes generating an optical signal 13, typically from an optical emitter 14. Step 64 includes transmitting the optical signal 13 through the encapsulant 18. In step 66, the optical signal 13 transmitted through the encapsulant 18 is diffracted to form a predesignated optical radiation pattern 37.

While the embodiments of the present invention have been illustrated in detail, it should be apparent that modifications and adaptations to these embodiments may occur to one skilled in the art without departing from the scope of the present invention as set forth in the following claims.